2000

Exploring the relationship between technology, instructional method and learner outcomes: an application of path analysis techniques

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Exploring the relationship between technology, instructional method and learner outcomes: An application of path analysis techniques

by

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A dissertation submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Education (Curriculum and Instructional Technology)

Major Professor: Gary D. Phye

Iowa State University

Ames, Iowa

2000

UMI Number: 9992448

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Graduate College
Iowa State University

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CHAPTER ONE: INTRODUCTION

There were many developments in educational technologies during the 20th century. The introduction of moving pictures, television and computers were greeted eagerly by those who thought they would revolutionize teaching and learning. Thomas Edison, speaking of the motion picture, predicted that it would "entirely replace the book in the classroom inside of 10 years." (as cited in Lajoie & Derry, 1993). The motion picture soon gave way to television which yielded, in the early 80's to the personal computer as the technological innovation that could form the foundation of extensive educational reforms.

During this period researchers were busy attempting to document the influence of computers on student outcomes. In 1991 Kulik and Kulik performed a meta-analysis of 254 studies that looked at the impact of computer-based instruction. They concluded that computer based instruction (CBI) generally produced positive effects on students. These effects included increases in student test scores and positive attitudes towards technology and teaching (p. 80). Researchers also reported that use of technology decreased the amount of time needed for instruction. Other researchers (Bangert-Drowns, Kulik & Kulik, 1985; Khalili & Sashaani, 1994; Liao & Bright, 1991; Ryan, 1991) also performed meta-analyses with similar results: all found positive effect sizes for the use of technology compared to traditional instruction. There were enough differences found in these groups that theorists sought to explain the effects from their personal, theoretical positions.

Richard Clark, the creator of the delivery truck analogy, explained that technology as a "mere delivery vehicle" cannot influence learning, therefore any seeming effect of technology on learning must instead be attributed to the teaching methods embedded in the technology (1983). Kozma agreed that it was not possible to attribute learning to the effects of technology alone, but believed that technology and methods effects could be separated in studies of learning. Some researchers in this field believe that Clark and Kozma are asking the wrong question. Representatives of this position include Robert Tennyson and David Jonassen who think the more appropriate question is: How can technology be used to greatest advantage in learning environments? rather than : Does technology make a difference in student learning outcomes? The ongoing debate between Clark and Kozma provides fertile grounds for exploration. As Kozma commented,

> I believe our research focus should be on the nexus of these two things: design and technology – media and method – not just one or the other. Neither alone is sufficient to sustain our field. It is the interplay of the two within the learning context that should be the focus of our research and theory. (2000, p. 19)

Purpose

The purpose of this study is to isolate the effects of technology use from the effects of instructional method on student learning. Within the context of this study "technology" refers to the use of computers, calculators and graphing calculators. Path analysis techniques will be employed to explore the relationships of applicable student characteristics, instructional methods, and technology use to learning outcomes in middle school mathematics.

Setting Of The Study

Data were collected for this study at a middle school in a small, rural, mid-western town. During 1999 the math department at this school adopted commercially developed problem solving exemplars for use in grades 6-8. Teachers received three days of training during the summer of 1999. This training included the use of the exemplars and scoring by means of rubrics. Teachers also selected six exemplars to be used for learning and assessment at each grade level.

The math teachers at the school have different levels of experience with using problem-based learning. The Jasper Woodbury videodisks have been used at the school for three years. The sixth grade teachers are in their third year of using this method, the seventh grade teachers in their second year, and the eighth grade teachers are new to it this year. The teachers work in grade level pairs and meet as a group to discuss problems of implementation. The more experienced teachers provide informal mentoring to the others.

The math exemplars all include the use of hand-held calculators and teachers report that students use these daily. Some computers are also available for use in the school, but access is limited. Many of the students report using computers at home.

Path Analysis

Path analysis was chosen to examine this data because it is a method useful in exploring the development of theory (Raykov & Marcoulides, 2000). . In this study the elements of several competing hypotheses are being tested to determine if they can provide enough explanatory power to form the basis of a theory relating technology use and instructional methods to student learning.

The model used for the analysis includes elements indicated by prior research to effect learning in mathematics: individual math achievement, motivation for learning in mathematics, self-efficacy with technology, socio-economic status, and individual technology use.

As path coefficients are calculated, the non-significant relationships will be dropped from the model. The remaining elements should provide an explanation for the relationship between instructional methods, technology use and student learning.

Summary

Within the instructional technology field there are three distinctly different schools of thought regarding the effect of technology use on learning. Clark believes technology has no effect on learning and likens it to a delivery truck that only conveys instructional methods and content. Kozma cites the theory of distributed cognition to explain his belief that technology does have an impact separate from the instructional methods employed. Educational psychologist Gavriel Salomon agrees and discusses two types of technology effects; effects of technology and effects with technology. The third position is that whether or not technology itself has an effect which can be measured, the use of technology is justified by other learning theories. Richard Mayer, another educational psychologist, supports this position and has developed a theory of multimedia that is based on research-derived theories of learning. The purpose of this study is to attempt to demonstrate that technology use can affect learning. The method employed will be path analysis that can calculate path coefficients that show the effect of variables with all other effects partialed out.

CHAPTER TWO: LITERATURE REVIEW

Over the past 30 years, hundreds of studies of the effectiveness of computer-based instruction (CBI) have been conducted. These individual studies have been reviewed and meta-analyzed repeatedly. Each such review or meta-analysis has produced further confirmation of the effectiveness of CBI in different forms, at different grade levels, and with different populations. Why, then, is the search for the effectiveness of computer based instruction still continuing and even escalating as politicians search for justification of multi-billion dollar expenditures? As the following review of the literature will demonstrate, the debate as it is now constituted, is not about whether or not computers can make a difference, but rather, concerns how to explain the difference that computers do make in student learning. The popular notion that the benefit of computers has not yet been established results from the domination of Richard E. Clark's oft-quoted theory that media are just "delivery vehicles" (Clark, 1983, p. 445).

Effectiveness Of Computer Based Instruction

Early Reviews

Vinsonhaler and Bass published one of the first reviews of computer-based instruction in 1972. They selected ten studies that used computer aided instruction of the drill and practice form, measured improvement using standardized tests in mathematics or language arts, and employed a basic experimental design utilizing control groups. All of the studies compared computer aided instruction to traditional instruction. Vinsonhaler and Bass concluded, "The effectiveness of CAI over traditional instruction seems to be a reasonably well-established fact in drill and practice for both mathematics and language arts, when performance is measured by SAT- and MAT-type tests" (Vinsonhaler & Bass, p. 31). The authors' recommendations for further research included the need to identify the "underlying bases" for the CAI effects, suggesting they could be the result of novelty, changes in teacher behavior, or changes in student behavior.

Another early summary of computer aided instruction studies by Edwards, Norton, Taylor, Weiss and Dusseldorp (1975) selected studies that used not only drill and practice, but problem-solving, simulation, or tutorial as well. The studies chosen compared computer-aided instruction to some other form of instruction. No information was provided regarding the design or assessments used in each study. Results were presented in a box-score fashion. Of the nine studies that reported on CAI used as a supplement to instruction, all 9 studies showed greater achievement for the CAI treatment. When CAI was used as a replacement for traditional instruction, half of the twenty studies showed greater achievement for the CAI group, 7 resulted in equal gains for the traditional and CAI groups, and 3 yielded mixed results. Other results of this review were that use of CAI results in time savings and that lower ability students profited more from drill and practice than did higher or average ability students.

Meta-Analyses

In the 1980's and 1990's several meta-analyses of computer-based education were published (Bangert-Drowns, Kulik, & Kulik, 1985; Khalili & Sashaani, 1994; Kulik & Kulik, 1991; Liao & Bright, 1991; Ryan, 1991). These acknowledge the work of Glass, McGraw and Smith (1981) and used standardized effect sizes to compare results of the studies. Studies for each meta-analysis were selected based on some common criteria including that studies had to employ experimental or quasi-experimental designs and yield quantitative data for comparison of groups. Other criteria that were applied uniquely to the meta-analyses included: restriction of grade level, restriction by date of publication, restriction of type of publication (journal, dissertation, ERIC, etc.) and inclusion of classroom-based studies rather than laboratory-based studies.

Typically, researchers also coded studies included in the meta-analyses so that comparisons of effect sizes could be made by particular groups. Building on the findings of other researchers, these comparison groups came to include: year of publication, grade level, number of subjects, duration of treatment, mode of production (drill & practice, tutorial, simulation, problem solving), sample selection, subject area, same or different teacher for included treatments, and type of assessment (standardized, or teacher created) (Khalili & Shashaani, 1994, pp.54-55).

These meta-analyses resulted in mean effect sizes for computer-based instruction (CBI) aggregated across all comparisons made in all studies. Mean effect sizes of the meta-analyses included in this review ranged from .309 to .40 favoring CBI over traditional and other forms of instruction. Using the standardized effect sizes as z-scores, this can be interpreted as placing the average score for students in the CBI treatment in the 62nd to 66th percentile compared to the 50th percentile of the average student in the control treatment.

Each meta-analysis contributed to the understanding of the effects of computer based education. Based on 51 studies of the effectiveness of technology in 5 types of CBI used in grades 6 - 12, the findings of Kulik, Bangert and Williams (1983) were consistent with earlier researchers in finding an average effect size of .32 and determining that computer based instruction saved time over traditional instruction. They contradicted Edwards, Norton, Taylor, Weiss and Dusseldorp (1975) who suggested that retention might be reduced in CBI. Kulik, et.al. also suggested that further study should be given to their near-significant findings that more recent studies, studies published in journals, and studies that were shorter in duration resulted in greater effect sizes. In addition, they suggested that disadvantaged and low ability students might benefit more from computer-based instruction than average or high ability students.

Bangert-Drowns, Kulik, and Kulik (1985) performed a meta-analysis of 42 studies of computer-based instruction in junior and senior high schools. They examined three types of computer-based instruction: computer assisted instruction (CAI), computer managed instruction (CMI) and computer enriched instruction (CEI). CAI and CMI were found to increase student scores from the 50th to the 60th percentile, while CEI was limited to a 50th to 53rd percentile increase. They also investigated effects of CBI on disadvantaged students and confirmed earlier suspicions that these students received greater benefit from this form of instruction. Bangert-Drowns, et. al. confirmed earlier findings that CBI produced positive effects on student attitudes. They also found a positive relationship between the date of studies and the strength of the effect size with more recent studies resulting in stronger effect sizes.

Kulik and Kulik (1991) chose 254 studies comparing learning of students in kindergarten through college in classes taught by computer based instruction or by traditional instruction. They found that CBI in a typical study increased scores of an average student on final examinations from the 50th to the 62nd percentile.

Other findings were that the greatest effect sizes were found in studies with a length of 4 weeks or less. Longer studies produced weaker effect sizes. Examination of study by publication type revealed greater effect sizes in journal publications than in dissertation studies. This was hypothesized to result either from editorial bias in favor of greater effect sizes, or lack of skill in student researchers. Kulik and Kulik also found greater effect sizes in studies which employed different teachers to teach the control and treatment groups. This finding, which was also mentioned by Khalili & Shashaani (1994), becomes a critical discussion point later in the development of theory to explain the differences between CBI and traditional instruction.

Ryan (1991) included 40 separate studies in her meta-analysis. Her goals were to clarify the achievement effects of computer use in elementary schools and to explore some of the variables that might increase its effectiveness. The mean effect size for this meta-analysis was .309, which would be a 62nd percentile placement for the average student in the study. Other findings included a significant difference between teachers that resulted from the amount of training they had received. The study revealed that training in amounts greater than 10 hours was best, and that fewer than 10 hours of training resulted in effect sizes which were weaker than groups with no training at all (p. 175). Ryan also urged further research to include more variables such as socio-economic status and type of hardware to explore the differential impact of technology.

Liao and Bright (1991) explored the impact of teaching computer programming on student acquisition of cognitive skills including planning, reasoning, and metacognitive skills. Sixty-five studies were included in the meta-analysis which resulted in an overall mean effect size of .41. Liao and Bright concluded that students gained cognitive skills as well as knowledge of programming when they studied a programming language.

Khalili and Shashaani (1994) included 36 studies of the effect of computer applications on student academic achievement. This meta-analysis yielded a mean effect size of .38. Other significant findings were that studies of 4-7 weeks duration yielded the strongest effect sizes (ES = 0.94) while the weakest were in studies of 1-3 weeks duration. Data were not reported for studies longer than 7 weeks. The mode of computer application with the strongest effect size was simulation (ES = .79) followed by problem solving (ES =

.41) and drill and practice (ES = .11). When different subject areas were compared, the strongest effect sizes were produced in studies using computers in mathematics (ES = .52).

Each meta-analysis resulted in positive effect sizes for computer based education over traditional methods of instruction. These included nearly 500 separate studies of the impact of computers on student achievement.

Hypotheses About Computer Based Instruction

Following years of study and printed discussions, opinions on the impact of computer technology on student learning have evolved into three basic groups. The first, led by Richard Clark, believes that technology cannot make a difference to learning. The second, led by Robert Kozma, believes that it can. The third group is comprised of others who believe, like Tennyson, that it doesn't matter if it can or not, because they have found a use for the technology and can justify it relative to learning theories or curriculum theories.

Richard E. Clark: Media And Methods Are Separate

In 1983 Richard E. Clark wrote an article about the effects of learning with media. In this article he first stated the now famous analogy "...media are mere vehicles that deliver instruction but do not influence student achievement any more than the truck that delivers our groceries causes changes in our nutrition" (p. 445). He continued, stating that the studies that showed increases in learning achievement through the use of CBI were confounded by the confusion of medium with method and by not controlling for the novelty of the medium. Clark concluded by recommending that no further media comparison research be conducted.

The influence of Clark's article can be seen in the Social Sciences Citation Index that showed 173 citations of this one article dating from 1983-1999. What seems incredible is that Clark did not conduct research to disprove or correct earlier researchers. He created a hypothesis. His hypothesis is based on the assumption that any learning that occurs as a result of student interaction with media is due to the instructional methods embodied within the media.

But does this hypothesis negate all the media studies that preceded and followed it? As evidence of the confounding of media and method, Clark offers that in studies in which the teacher was the same for the control and the treatment conditions, "the positive effect for media more or less disappears" (p. 448). This, according to Clark, is explained by the reduction of variance that might result from using different teachers for the control and treatment groups. Khalili and Shashaani (1994) also found a significant difference between effect sizes of groups taught with the same teacher and groups with different teachers. The effect sizes were .45 for the group with different teachers and .35 for the group with the same teachers. These convert to percentile ranks of 68 and 64 respectively for the average student in the groups. While this difference was found to be statistically significant, it certainly indicates strong positive effects of technology in both groups.

Kulik and Kulik offered two more competing explanations for these findings in 1991: (1) more skilled teachers may have been chosen to teach the computer based treatment groups and less skilled teachers assigned to the traditional instruction group, or (2) there was "treatment contamination" in the single teacher experiments (p. 89). Treatment contamination refers to the possibility that a teacher who participated in the treatment condition might have benefited from that involvement and this could change the way information was presented in the traditional condition.

Without further information regarding the participating teachers and their performances, it is not possible to determine whether Clark's or Kulik and Kulik's explanations are correct. In the absence of that proof, it is not reasonable to reject the possibility of an effect on learning that is created solely by the medium employed.

Clark's other allegation, that effect size differences were due to novelty, rested on the evidence that shorter studies showed stronger effect sizes, and longer studies resulted in weaker effect sizes. Clark's explanation is only one of several plausible explanations. For example, shorter studies may be more focused than longer studies, or with longer studies there could be more opportunities for confounding events (class cancelled due to snow days, increased absences due to flu season, etc.). Again, further studies were not conducted to determine which explanation was most supported by the evidence.

Following Clark's article, others stepped forward to offer theories to explain the impact of computers and other media on learning. This resulted in a special issue of Educational Technology Research & Development in 1994 devoted to the debate on whether or not technology could impact student learning. It was in these articles that the three above-mentioned positions emerged.

Robert Kozma: Attributes and Methods Interact

In contrast to Clark's view of instruction as "delivering" information (Clark, 1983), Robert Kozma approaches learning from a constructivist perspective (1991). In the media debate, Kozma theorizes that specific attributes of different media interact with instructional methods to create opportunities for learners to construct knowledge.

Kozma looks to the theory of distributed cognition to describe the interaction between the learner and the medium. Distributed cognition theory holds that the elements of a learning system all share in the knowledge creation process. This includes the learners and the devices the learners employ (Winn & Philips, 2000).

Some devices share in knowledge creation through easing the cognitive load for the learner by performing calculations, re-arranging data, or other high demand cognitive tasks. Because working memory is limited and cognitive overload results in failure to learn, this sharing of the cognitive load enables learners to do more (Sweller, Chandler, Tierney, & Cooper, 1990; Baddely, 1992, Sweller & Chandler, 1994).

Besides supporting part of the cognitive load of a task, devices can also impact learning by the use of particular symbol systems (Salomon, 1979). In a second article, Salomon describes effects *with* technologies and effects *of* technologies (1991). Effects *with* technology refer to the learning accomplished by the individual interacting with the technology. An example of these effects include being able to model complex systems, through the use of software, that would not be possible without such augmentation. Effects *of* technology includes a "cognitive residue" left behind as the improvement of skills, strategies, or understanding. An example of this might be an ordered approach to calculations that an individual uses for mental math after prolonged use of an abacus. Stated another way, effects with technology are seen in the products the learner creates while using the technology. The effects of technology are seen when the technology is no longer present.

Kozma's hypothesis is that the people, methods, and devices used in a learning environment ail impact the student learning outcomes. Further, he believes the effects of technologies can be separated from the effects of methods.

Computers Can Be Used To Produce Desired Learning Outcomes

Jonassen also uses distributed cognition theory to support the contention that technology can have an effect on learning. Unlike Kozma, however, Jonassen believes that these effects are intertwined and inseparable. He is also part of the group of researchers who believe it is no longer appropriate to ask the media effectiveness question. Instead, they have justified the use of computers and other technologies by the methods they make possible and the curriculum elements they can create. In particular, Jonassen prefers constructivist learning environments and demonstrates how they can be created with computer technologies. For Jonassen, the most important feature in a learning environment is the student who is responsible for creating his/her own knowledge not the technology that the student uses (1994).

Mayer (2000) supports this view and discusses two approaches to technology studies. The technology-centered approach focuses on what the technology can do and those who adhere to this approach perform media comparison studies. The learner-centered approach examines how technology can be utilized to promote student learning. Mayer favors the learner-centered approach. This approach uses research on the learning process to inform how technology can be incorporated effectively into a learning environment (p. 553). In particular, Mayer has developed a theory of multimedia design that rests on 5 research-supported principles. The Multiple Representation principle: it is better to present information in 2 modes of representation instead of one. The Contiguity principle: words and pictures presented together are more powerful than when presented separately. The Split-Attention principle: when animations are used, explanations should be presented auditorily instead of in on-screen text so the learner can attend to the animation. The Individual Differences principle: individuals respond differently to these principles depending upon their knowledge and skills. And the Coherence principle: when using multimedia, keep explanations simple (p. 559-561).

Tennyson is another who believes that computers and other technologies should be enfolded into the curriculum in places that most suit them. He has devised an interlinked system of learning objectives, teaching strategies, information and technologies that work together to produce desired learning outcomes (1994). Tennyson is also not interested in deciding what separate impact the technologies have, he accepts that they have certain properties that are supported by learning theory and that is sufficient reason to use them.

Morrison, Reisser and Schrock are three other members of this group. They approach technology use as instructional designers and allocate technology use where indicated by the special attributes or characteristics of the technology or software. Their concerns are with achieving desired outcomes, not with determining which element of the plan was responsible for the learning. (Morrison, 1994; Reisser,1994; Schrock, 1994)

Questions for Theory Development

Jonassen, Tennyson, Morrison, Reisser and Schrock are no longer interested in whether or not technology influences learning. They use it as a tool. Clark and Kozma are the leaders in the technology debate and the hypotheses presented by these figures in the technology debate focus attention on the differential contributions of technology and instructional method to student learning. Each has offered an hypothesis but neither has produced empirical evidence to substantiate his position. What remains to be established is whether or not any effects of technology on learning can be separated from any effects of specific instructional methods. This study proposes to attempt that separation by employing path analysis. The study will focus on middle school math classes that are engaged in problem solving activities that conform to constructivist learning theory and that include the use of technologies. The particular technologies employed in this design are calculators and the Jasper Woodbury laser disks.

Kozma describes the need for a study such as this one in a recent article:

> Understanding the relationship between media, design and learning should be the unique contribution of our field to knowledge in education. This understanding is the base of our practice, our theory, and our research. But if we choose to continue to ignore media considerations in our thinking, if we continue to treat them as mere delivery devices, both our thinking and our field will be impoverished. Our future will be doubtful and others will take our place. (2000, p. 14)

Mathematics Curriculum and Technology

Several important factors are included in the math program under study. One is the use of math exemplars for teaching. These are commercially prepared units that present problems that might be encountered in business or personal lives. These problem solving units are used as part of a constructivist learning environment to challenge students to gain the skills and strategies required to solve the problems. A second factor is the use of the Jasper Woodbury set of problems that are delivered via video disk. Designed as a supplement to math curricula by the Cognition and Technology Group at Vanderbilt University, Jasper Woodbury also promotes problem solving within a constructivist learning framework. The third factor which is prominent in the math program for this study is the daily use of hand-held calculators. The following sections discuss each of these factors.

Constructivist Approach To Problem Solving

Constructivist approaches to learning vary widely, but Roblyer, Edwards, and Havriluk (1997) describe it as follows:

> …constructivists propose arranging instruction around problems that students find compelling and that require them to acquire and use skills and knowledge to formulate solutions. Constructivists call for more emphasis on engaging students in the process of learning than on finding a single correct answer (p. 58).

Problem Solving Activities In Math Instruction

The use of problem solving activities in math instruction is one of the National Council of Teachers of Mathematics standards (National Council of Teachers of Mathematics [NCTM], 2000). Solving problems helps students develop "condition-action pairs" which specify the conditions under which certain mathematical actions are appropriate. This practice helps to eliminate "inert knowledge" by providing activation cues (Bransford, Zech, Schwartz, Barron, Vye, & CTGV, 2000).

Research On Technology Use In Mathematics

In 1998 the National Assessment of Educational Progress (NAEP) in mathematics included a survey of technology use by 4th and 8th grade students. This national sample was analyzed by Wenglinsky to determine if technology use were correlated to learning in mathematics. Amongst his conclusions were: the use of computers is associated with "significant gains" in mathematics learning, especially when they are used for higher-level thinking skills development (p. 32). This was also seen with 8th grade students who had home computers.

Wenglinsky also found that socio-economic status (SES) was a significant factor in the study. Poor students, members of minority groups and urban students were more likely to use drill and practice software than programs to develop higher order thinking skills, thus limiting their gains in mathematics learning. (1998, p. 32). Of all the elements of the model studied, SES had the largest correlation to achievement for both 4th and 8th grades (p. 30).

Calculator use was investigated by a number of researchers whose studies were combined in a meta-analysis by Hembree and Dessart (1986). They combined the outcomes of 79 separate studies of calculator use and classified them by the dimension of learning studied (acquisition, retention, or transfer of knowledge). Effect sizes were computed for all comparisons. These effect sizes were combined in sets that represented the research questions and the groups were examined for homogeneity. The homogeneity of the groups was reported rather than the effect sizes.

Hembree and Dessart found that the use of hand-held calculators increased basic computation skills for all students except 4th graders. The use of calculators in problem solving also showed a large positive effect for computation and the selection of appropriate steps in generating a solution. Differential effects were found for students of different abilities. Average students benefited most from use of calculators in learning basic skills, while low and high ability students benefited most in problem solving (1986, p. 95).

Hembree and Dessart concluded that the benefit of hand-held calculators in mathematics instruction was sufficiently established and that future research should concentrate on discovering the most effective procedures for their use (1986, 97).

Summary

A number of studies have been done to determine whether or not instructional technologies have an impact on student learning. These studies usually compared traditional instruction to instruction which included computers. As more and more studies became available, they were combined in meta-analyses to examine the effect sizes of any differences between these two types of instruction. All of the meta-analyses produced positive effect sizes for the use of computers in learning. Mean effect sizes of the meta-analyses included in this review ranged from .309 to .40 favoring CBI over traditional and other forms of instruction. Despite this, prevailing thought is that computers have not been shown to be effective in learning. This is the result of the predominance of Richard Clark's hypothesis that any change produced by computer-based instruction must be due to the instructional methods contained in the programs. Competing hypotheses are offered by Kozma and Jonassen. Kozma believes that there is an effect of the use of technology which can be examined separately from the effect of instructional methods. He is supported in this position by the theories of distributed cognition and the work of Salomon on effects *with* technology and the effects *of* technology. Jonassen's position is that there may be an effect, but it is so entwined with the effects of instructional method that it cannot be measured separately. He further contends that the use of technology is supported by other learning theories so the debate about effects of technology becomes unimportant.

Also discussed is the problem solving approach of constructivist learning theorists. The National Council of Teachers of Mathematics also recommends this approach. Other recommendations of the NCTM include the use of calculators in mathematics. Research on calculator use demonstrates an impact on learning basic skills and problem solving strategies. Wenglinsky also demonstrated that technology use is associated with increases in learning in mathematics.

The goal of this study was to contribute to the discussion of technology effects, evidence for the impact of technology that is separate from the impact of the instructional methods employed. This was attempted through careful research design and the employment of path analysis techniques. Data were collected in a middle school math program that employed constructivist problem solving learning strategies and also enfolded the NCTM recommendation of daily calculator use.

CHAPTER THREE: METHODOLOGY

The reported project is a correlational study that employed path analysis to ascertain the impact of computer-based instructional technology use and instructional method on student learning outcomes in middle school math classes. The unit of analysis employed within this study was the individual student. It was hoped that this approach would yield more detailed information about the effects of computer-based technology use and instructional method for different types of students than a study that collapsed individual differences into a classroom unit of analysis.

According to Martella, Nelson, and Marchand-Martella (1999), there are three critical issues in designing correlational research: (1) creating an hypothesis based on a review of the literature, (2) selecting a group of participants that is homogeneous with respect to the desired variables, and (3) ensuring that the instruments used for data collection possess adequate reliability and validity.

Hypothesis

Path analysis techniques will show a positive correlation between the use of computer-based instructional technology and learning. Further, it is hypothesized that technology use will interact with instructional methods to produce learning outcomes.

Participants

A total of 461 students participated in this study. The group consisted of 372 students from grades 6-8 at a mid-western middle school and 89 ninth grade students from a mid-western high school. The students at the middle school included all students enrolled in math classes at the 6^{th}, 7^{th} and 8^{th} grade levels. The high school students consisted of all 9^{th} grade students enrolled in a library skills class during one quarter of the school year. The 9^{th} grade students provided a separate sample for test/retest reliability.

Although the middle school and the high school are in different districts, the students can be classified by Piaget's theory into the Formal Operational stage that includes students aged 11 and older. Children in this age group are developing logico-mathematical structures and the ability to reason through hypothetical situations (Elliott, Kratochwell, Cook & Travers, 2000, p. 48). Piaget's stages have been under scrutiny by recent researchers who wonder whether the stages are valid, whether they emerge at the same age for everyone, or whether they are in fact dependent upon individual development and exposure to domain specific knowledge and task demands (Beck, 1997). In this study, Piaget's stages are used to describe development of a large group of students in a gross way. As a group, students of these ages are more likely to have developed the seriation, thinking reversal, and concrete reasoning abilities of the concrete operational stage and are beginning to develop the abilities associated with the formal operational stage. Whether a specific individual has mastered a specific skill or not is unimportant to the study.

Both of the groups involved in the study represent convenience samples, which prohibits the generalization of results to any other population, unless it can be demonstrated that these students are representative of a larger population.

Instruments

Student Technology Use

The Student Technology Use (STU) instrument was designed to measure the penetration of instructional technologies into the lives of students. It consisted of 28 items arranged in 2 sections. The first section addressed how often during a typical week a student used a computer or graphing calculator at home and in various locations at school. The second section asked students to report the number of hours in a typical week spent using computers or graphing calculators in various ways.

Teachers at the middle school chose to set aside one class period to administer the STU with its appendices (described later). Teachers read each item aloud and answered student questions as they arose.

One of the goals of this study was to ascertain if the STU possessed adequate reliability and validity.

Self-Efficacy with Technology

The first of the appended sections was a measure of self-efficacy with computers and calculators consisting of 16 items. Each item wasd a statement to which students indicated their agreement/disagreement using a 5 point Likert scale. This section was based on the work of Albert Bandura (1996) who demonstrated that feelings of self-efficacy influence student achievement.

General Motivation for Learning Math

The second section appended to the STU consists of 31 items that assessed general motivation for learning in math. The 31 items were rated using a 7 point Likert scale indicating the how well the item described the respondent ('not at all true of me' to 'very true of me'). There were 6 subscales and a total that were calculated from this data. The six sub-scales of the motivation scale were: intrinsic goal orientation, extrinsic goal orientation, task value, control of learning beliefs and self-efficacy for learning and performance. Reliability coefficients were reported by sub-scale with alpha values ranging from .62 to .93 (Pintrich, Smith, Garcia & McKeachie, 1991.

This instrument was modified to focus on math class. An example of the modification was:

Original: In a class like this, I prefer course material that really challenges me so I can learn new things.

Modified: In math class, I prefer course material that really challenges me so I can learn new things.

The STU survey and its appendices yielded 11 scores for each student: one for the number of times per week instructional technologies were used, one for the number of hours spent using IT in various ways, a total score (sum of times/week and hours/week), a score for self-efficacy with technology and scores for general motivation for learning in math that consist of 6 subscales plus a total.

Math Achievement

The Iowa Test of Basic Skills math subtests for concepts/data analysis, problem solving, and math total national standard scores were used as indicators of students' past math achievement.

Socio-Economic Status

Socio-economic status was defined by a student's free/reduced lunch status. This is a nationally recognized measure of economic status as it is based on a test of a family's monthly income.

Procedures

The use of path analysis makes the timing of data collection critical. To avoid confounding the results, independent variables must be collected before the dependent variables. This practice was adhered to in this study with all of the exogenous variables being collected before the endogenous ones (Figure 1).

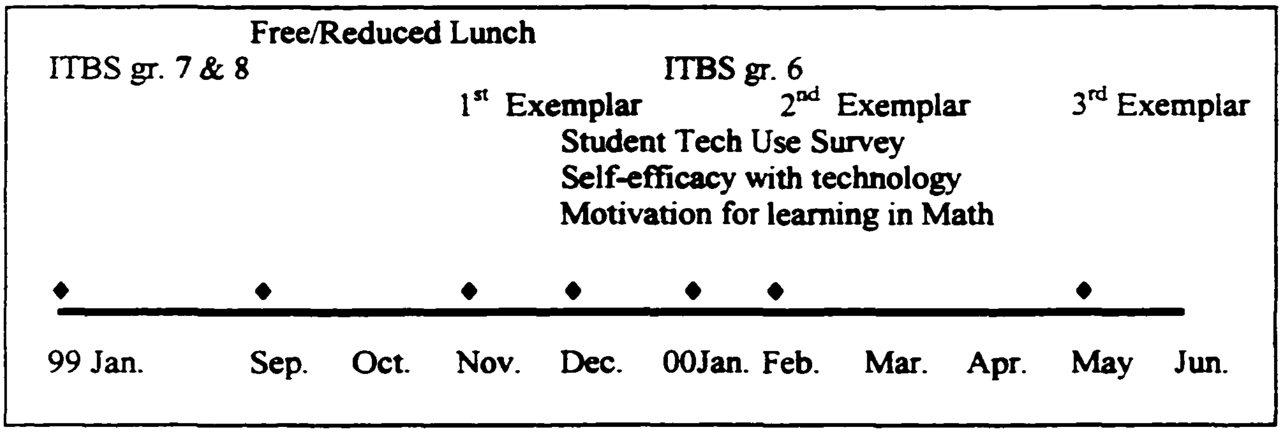


Figure 1. Data collection timeline.

The middle school in this study purchased a series of commercially prepared math problem solving exemplars. The particular exemplars used at each grade level were chosen at the district level to match the district Standards and Benchmarks for math. These exemplars included the use of calculators to aid in problem solving. Students used calculators daily in all math classes. In addition, the Jasper Woodbury problem solving videodisk was employed for a two-week period in April by the 6th and 7th grade math classes. The eighth grade students did not use Jasper Woodbury during the study, but the eighth grade students who had attended this school for 6th and 7th grades had used it during the previous two years.

Students in the middle school completed a total of 6 math exemplars during the year. These were paired so that the first exemplar was used for instruction, the second for assessment. The particular math exemplars were different for each grade level. The math teachers assigned math exemplar scores utilizing rubrics that were generated at the school district level.

Three types of data were collected during this study:

1. Background information on students consisting of their socio-economic status, their math achievement, their self-efficacy with computers and calculators, and their general motivation for learning in math.
2. Scores on problem solving math exemplars consisting of a total and 4 sub-scores for accuracy, communication, reasoning and understanding. The first exemplar score is used as a background variable and the second and third exemplar scores are used as the learning outcome.
3. Student technology use as indicated by scores on the STU survey.

The SES measure –free/reduced lunch status – was collected for all middle school students. Free and/or reduced lunch status was scored as 1 and full price lunch status was scored as 2.

The ITBS scores used for this study were the National Standard Scores for math concepts/ data analysis, problem solving, and math total scores. ITBS math scores were gathered for all middle school students. The 7th and 8th grade scores were from January 1999, while the 6th grade scores were from January 2000.

The three math exemplar scores were generated in November, March, and May.

The middle school students completed the STU survey in December of 1999. The high school students completed the STU survey twice during April of 2000. The survey administrations were one week apart.

Summary

This study examines data collected in six middle school classrooms. Students in all the classrooms were exposed to math problem solving exemplars in learning and assessment. These exemplars represent the instructional methods. Students also used calculators daily in the classroom and computers at school and at home. Their technology use was measured using the Student Technology Use (STU) survey. Other information gathered about each student included socio-economic status, math achievement, motivation for learning in math, and self-efficacy with technology. The unit of analysis in this correlational study was the individual student.

CHAPTER FOUR: RESULTS

The statistical efforts in this study fell under two distinct headings. First was the need to establish the psychometric properties of the Student Technology Use survey; the second was to conduct a path analysis to determine the impact of technology use on student learning outcomes. Although the self-efficacy measure included in the STU was initially examined as a separate exogenous variable, it was highly collinear with the total STU (TSTU) and its factors, so the self-efficacy was combined with the STU and the factor analysis was repeated. The result was the identification of fewer factors with items loading heavily on those factors. This was considered an improvement.

Description of Sample

The middle school sample of students was 51% female and 49% male. Of the total of 372 students, 103 (27.7%) were in 6^{th} grade, 121 (32.5%) were in 7^{th} grade, and 148 (39.8%) were in 8^{th} grade. Just over one quarter (27%) of the students were on free or reduced lunch.

On average, students reported having 6 years experience using computers. Most of their computer use takes place at home where they report using a computer 10 times a week compared to 3 times a week in their classrooms, 4 times a week in the computer lab, 3 times a week in the media center and 4 times a week at a friend's or relative's house or other location. Just nine percent of the students reported they did not own a computer.

When reporting the number of hours they spent on specific tasks utilizing a computer or graphing calculator, student estimates ranged from a low of zero hours to a high of 130 hours each week. With such a positively skewed distribution the mean is not a very informative statistic, the median and the mode, being more resistant to outliers, are more appropriate. The median number of hours students reported using computers and graphing calculators was 23.5 hours (N=372). The mode was 8 hours (N=372).

Another consideration in examining this data was whether or not the students were accurately reporting their hours of use. Examination of the frequencies for this item showed that 10 students (3%) reported an average of zero hours of use in a week while 21 students (6%) reported using the computer/graphing calculator more than 10 hours a day. These are certainly extremes of usage, but as several of the items on the STU asked for the number of hours spent using a computer/graphing calculator for activities that could occupy large amounts of time (creating web pages, creating graphics, playing games, participating in chat rooms, etc.), these outliers may represent actual usage for this small number of students.

The obvious skewness and kurtosis of this data was handled in two ways. First, the responses were converted to z-scores and TSTU (total student technology use) represents the mean of z-scores for each student. Secondly, for purposes of the path analysis, the natural log of the TSTU was used. These transformations resulted in distributions that were much more normal looking and more suitable for the calculations that followed.

Instrument Development

Reliability

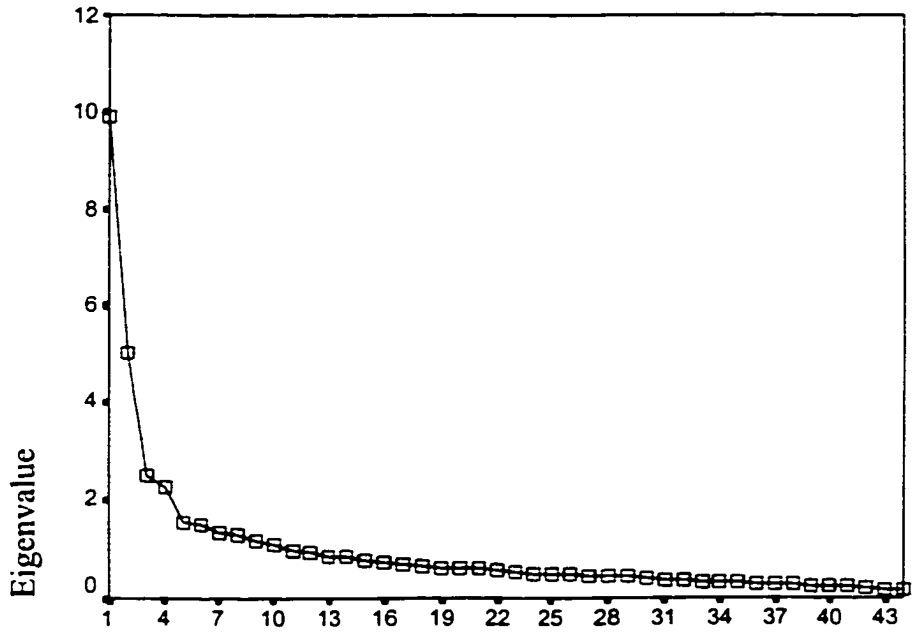
To examine the internal reliability of the STU, a Cronbach alpha was computed using the middle school responses to the STU. The calculated value of the Cronbach alpha was .88.

To determine the test-retest reliability of the STU, the high school repeated administrations of the STU were used. The Pearson product moment correlation between the two administrations of the instrument was .86 ($p < .01$)($n = 48$).

Factor Analysis

To examine the validity of the STU, a factor analysis was performed using the maximum likelihood extraction method and varimax rotation. Maximum likelihood is a rigorous extraction method that results in parameter estimates that are the most likely to have produced the observed correlation matrix provided the sample is from a distribution that is multivariate normal. Varimax rotation is an orthogonal rotation method that produces factors that are not correlated with each other. In addition, the varimax rotation method enhances the interpretability of the resulting factors by minimizing the number of variables that have high loadings on a factor (Norusis, 1993).

The initial extraction was set to examine factors with Eigenvalues greater than 1.0. This initial extraction produced 10 factors that explained 62% of the variance. Examination of the Scree plot (Figure 2) showed that 3 or 4 factors might be a more workable solution that



Factor Number

Figure 2. Scree plot of possible STU factors.

would still explain approximately 40% of the variance. Resulting extractions and rotations produced a final analysis that strongly identified 3 factors that explained 36% of the variance. Factor one (volume of computer/graphing calculator use) accounted for 13% of the total variance. Factor two (self-efficacy in using computers and graphing calculators) accounted for another 13% and Factor three (the Internet) for 10% of the explained variance.

Table 1. Initial Eigenvalues

Factor	Total	% of Variance	Cummulative %
1	9.910	22.523	22.523
2	5.041	11.457	33.980
3	2.487	5.652	39.632
4	2.261	5.139	44.771
5	1.548	3.518	48.289
6	1.473	3.349	51.638
7	1.338	3.041	54.679
8	1.291	2.934	57.613
9	1.185	2.693	60.306
10	1.077	2.448	62.754

Table 2. Factor loadings of all items on Student Technology Use instrument (n=372). Values less than .10 are not shown.

Item #	STU Item	Factor 1 Volume	Factor 2 Self-eff.	Factor 3 Internet	Communalities
3q	Hours practicing basic skills	**.652**			.434
3m	Hours exploring equations and figures	**.627**			.403
3b	Hours using educational software	**.609**			.388
3l	Hours analyzing data with spreadsheets	**.583**	.125	.150	.378
1d	Times using computer in media center	**.577**		.118	.350
3g	Hours spent learning to use software	**.532**		.134	.303
3k	Hours spent creating multimedia presentations	**.512**		.195	.300
3s	Hours spent creating graphics	**.510**	.144	.268	.353
3n	Hours spent modeling thinking	**.508**	.102	.101	.279
1e	Times using computer/calculator in other locations	**.508**		.375	.401
3r	Hours computer used for desktop publishing	**.493**	.130	.199	.299
3o	Hours spent running educational simulations	**.490**	.102		.251
1c	Times using computer in computer lab	**.476**		.181	.259
3h	Hours spent practicing keyboarding skills	**.464**			.220
3j	Hours using word processor for school	**.416**		.302	.267
1b	Times using computer in classroom	**.352**			.133
2b	Times using graphing calculator at school	**.303**			.106
2a	Times using graphing calculator at home	**.273**			7.752E-02
5g	Confidence practicing estimation w/ calculator		**.763**		.590
5h	Confidence using calculator to look for patterns		**.740**		.551
5f	Confidence using basic calculator functions		**.714**		.515
5a	Confidence doing Internet research		**.622**	.457	.605
5e	Confidence using a word processor		**.613**	.132	.397
5m	Confidence using spreadsheets		**.604**	.202	.408
5i	Confindence using calculator to find square roots		**.600**		.362
5p	Confidence creating graphics	.197	**.578**	.138	.392
5o	Confidence doing desktop publishing	.153	**.548**	.169	.353
5c	Confidence using keyboard		**.525**	.100	.286
5d	Confidence conducting routine maintenance	.157	**.498**	.293	.358
5j	Confidence using calc. to graph linear functions	.102	**.447**	.183	.244
5l	Confidence using PowerPoint	.195	**.412**	.314	.306
5k	Confidence using HyperStudio		**.407**	.322	.272
3c	Doing personal Internet research	.180	.135	**.703**	.545
3e	Emailing friends and relatives	.219		**.681**	.521
3t	Participating in chat rooms	.213		**.666**	.495
5b	Confidence in using email		.488	**.593**	.598
3p	Hours spent creating web pages	.305	.109	**.543**	.400
5n	Confidence creating web pages	.127	.420	**.529**	.473
1a	Times using computer at home	.147	.176	**.498**	.300
3d	Hours doing Internet research for school	.349		**.458**	.338
3f	Hours emailing students/resource for school	.349		**.432**	.314
3i	Hours performing maintenance, virus removal	.354	.186	**.417**	.334
3u	Hours using listserves	.363		**.396**	.288
3a	Hours spent playing games	.226	.162	**.325**	.183

Model Development

Discriminant Analysis

As described, this study combined the results of math exemplars at grades 6, 7, and 8. Because of the possibility of confounding due to differences in curriculum and teacher experience, discriminant analysis was employed to determine if there were any significant differences between these 3 groups. All of the variables were studied and Box's M was calculated to determine if the population covariance matrices were equal.

The discriminant analysis model was estimated with grade level as the dependent variable and the independent variables as shown in Table 3. The three grade levels were alike on 3 important variables: SES (free/reduced lunch status), TMOT (total motivation for math) and TSTU(volume of technology use). The other variables showed differences between the 6^{th}, 7^{th}, and 8^{th} graders. Many of these results were expected as ITBS math scores of 8^{th} grade students would reasonably be expected to be higher than those of 6^{th} or 7^{th} grade students due to maturation and learning.

Table 3. Tests of Equality of Group Means (n=372)

Variable	Wilk's Lambda	F	df1	df2	Sig.
SES	.993	1.263	2	369	.284
MCNS	.932	13.362	2	369	.000
MPNS	.928	14.257	2	369	.000
TSTU	.998	.444	2	369	.642
TCSE	.969	5.968	2	369	.003
TMOT	.991	1.763	2	369	.173
UNDER1	.946	10.572	2	369	.000
REASON1	.625	110.525	2	369	.000
ACCUR1	.767	56.004	2	369	.000
COMM1	.776	53.136	2	369	.000
UNDER2	.811	42.988	2	369	.000
REASON2	.924	15.220	2	369	.000
COMM2	.807	44.059	2	369	.000
ACCUR2	.848	33.100	2	369	.000
UNDER3	.834	36.667	2	369	.000
REASON3	.978	4.064	2	369	.018
COMM3	.892	22.239	2	369	.000
ACCUR3	.890	22.793	2	369	.000

Box's M for this group was significant. Box's M = 989.370, F = 2.692, df1 = 342, df2 = 310346.5, p <.01) indicating the population variances were not equal across the 3 groups. This might have been a reason to reduce the sample used for the path analysis except for the finding that this model captured the differences between groups sufficiently that group membership could be accurately predicted 82% of the time. (Table 4) Based on the strength of the predictions made possible by the model, the decision was made to continue with the path analysis using all three groups.

Table 4. Predicted Group Membership (n=372)

Grade		6	7	8	Total
6	n	81	6	17	104
	percent	77.9	5.8	16.3	100
7	n	5	101	15	121
	percent	4.1	83.5	12.4	100
8	n	10	13	124	147
	percent	6.8	8.8	84.4	100

Path Analysis

Path analysis employs regression procedures for the purpose of determining the relationships between variables in a model. The model is composed of elements related to a construct through theory and it is tested using path analysis. In this study the elements of several competing hypotheses are being tested to determine if they can provide enough explanatory power to form the basis of a theory relating technology use and instructional methods to student learning.

Path analysis shows not only the direct effects of exogenous variables on the endogenous ones, but also the indirect effects. The process of path analysis results in path coefficients from which the effects of other variables are partialed out. Typically, a full model is estimated initially, following which a more parsimonious model is developed. Path coefficients which are not significant are dropped from the model,; this provides a means of testing elements of theory as only the significant relationships are retained. Path coefficients provide evidence that can be used in causal statements about the relationships between variables (Asher, 1983).

Path analysis has been employed in educational research by Pajares (1996) who used it to test the role of self-efficacy in mathematical problem-solving performance of gifted middle school students.

Path analysis was conducted using LISREL 7.0 software to examine the possible predictive and mediational role of technology use on learner outcomes. The outcome of interest is the score of exemplar 3. The initial model is composed of elements that are known (see chapter two) to impact problem solving performance: SES, motivation, and prior achievement in math as well as the total of exemplar one. All possible pathways were tested and only the elements producing significant path coefficients were retained in the final model.

The elements of the path analysis are related to the hypotheses discussed earlier in the following ways: educational method is represented by the exemplars 1-3 which embody the constructivist approach to learning mathematics; technology use is represented by the TSTU which also includes self-efficacy with technology. A finding that exemplars 1 and 2 directly impact the specified outcome, exemplar 3, (and the absence of impact of TSTU) would support the assertion that method alone is responsible for learning outcomes and that technology may be a "mere vehicle" for the delivery of method. On the other hand, if TSTU directly or indirectly impacts the exemplars, it may be asserted that technology may convey more than just the instructional methods, but may impact learning in some separate way.

Several models were examined in the process of path analysis. The outcomes of those examinations and the outcome of the factor analysis of the STU prompted the selection of the final model.

The elements of the model are as follows:

SES = socioeconomic status as represented by free and reduced lunch status

MCNS = math concepts/data analysis score from ITBS expressed as a national standard score

MPNS = math problem solving score from ITBS expressed as a national standard score

TMOT = total motivation for learning mathematics

TOTAL1 = score on the first exemplar

TOTAL2 = score on the second exemplar

TOTAL3 = score on the final exemplar

FACTOR1 = from STU , factor described as volume of computer/graphing calculator use

FACTOR2 = from STU, factor described as self-efficacy in use of computer/graphing calculator

FACTOR3 = from STU, factor described as Internet use

Of these 10 variables, 5 are exogenous (SES, TMOT, TOTAL1, MCNS, MPNS) and 5 are endogenous (TOTAL2, TOTAL3, FACTOR1, FACTOR2, FACTOR3). Descriptive statistics for all 10 variables are shown in Table 5 and Table 6 presents intercorrelations among them.

Table 5. Descriptive Statistics for Model Variables (N=372).

Model Variables	Mean	Std. Deviation
socioeconomic status	1.73	.45
math concepts national standard score (MCNS)	240.87	24.41
math problem solving national standard score (MPNS)	246.65	31.12
total motivation(TMOT)	139.88	25.30
total score on exemplar 1 (TOTAL1)	10.57	2.93
total score on exemplar 2 (TOTAL2)	9.72	2.71
total score on exemplar 3 (TOTAL3)	9.05	3.14
ln Factor 1 (FACTOR 1)	2.30	9.18E-02
ln Factor 2 (FACTOR 2)	2.30	.10
ln Factor 3 (FACTOR 3)	2.30	9.7E-02

Full Model

The final full (saturated) model is represented in Figure 3. Significant paths are indicated with an asterisk. This model was reduced by removing the non-significant paths and recalculating the remaining path coefficients. The full model is a saturated model that takes into account all possible effects, both direct and indirect, of the variables. For this reason, the model fit statistics such as the χ^2 do not provide meaningful information as $\chi^2 = 0$ because the estimated covariance matrix exactly reproduces the sample covariance matrix.

Table 6. Correlations between all model variables (n=372).

		SES	MCNS	MPNS	TMOT	TOTAL1	TOTAL2	TOTAL3	LNFAC1	LNFAC2	LNFAC3
SES	Pearson Correlation	1.000									
	Sig. (2-tailed)										
MCNS	Pearson Correlation	.175**	1.00								
	Sig. (2-tailed)	.001									
MPNS	Pearson Correlation	.141**	.715**	1.000							
	Sig. (2-tailed)	.007	.000								
TMOT	Pearson Correlation	.059	.153**	.127*	1.000						
	Sig. (2-tailed)	.256	.003	.014							
TOTAL1	Pearson Correlation	.115*	.047	.012	-.006	1.000					
	Sig. (2-tailed)	.026	.362	.812	.901						
TOTAL2	Pearson Correlation	.151**	.431**	.324**	.264**	-.044	1.000				
	Sig. (2-tailed)	.003	.000	.000	.000	.402					
TOTAL3	Pearson Correlation	.170**	.458**	.415**	.228**	-.014	.576**	1.000			
	Sig. (2-tailed)	.001	.000	.000	.000	.789	.000				
LNFAC1	Pearson Correlation	-.102	-.119*	-.124*	.142**	-.036	-.072	-.056	1.000		
	Sig. (2-tailed)	.050	.021	.017	.006	.487	.166	.278			
LNFAC2	Pearson Correlation	.078	.200**	.254**	.267**	.007	.145**	.136**	-.005	1.000	
	Sig. (2-tailed)	.141	.000	.000	.000	.894	.005	.008	.929		
LNFAC3	Pearson Correlation	.075	-.006	-.022	-.051	-.068	-.121	-.102	-.049	.003	1.000
	Sig. (2-tailed)	.148	.913	.673	.326	.189	.020	.050	.347	.956	

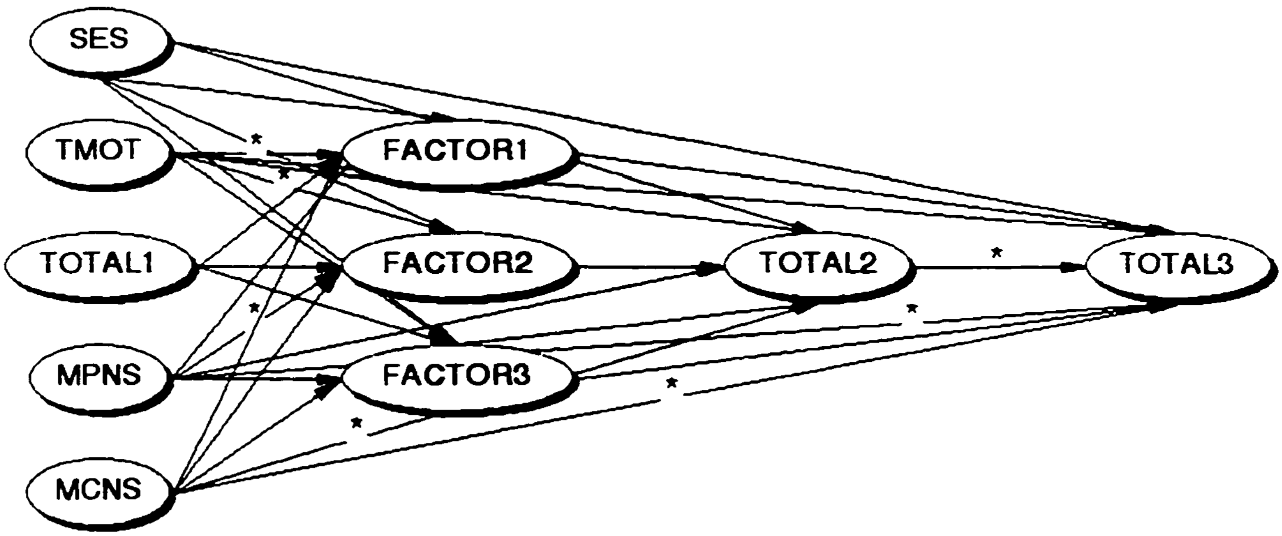


Figure 3. Saturated model

Another indicator that is helpful in saturated models is the coefficient of determination (also called R^2).The structural equation accounted for 43% of the variance (R^2=. 431) in this model. The R^2 of each endogenous variable shows how much of the variance of that element is explained by elements of the model: FACTOR 1 R^2=.052, FACTOR2 R^2=.122, FACTOR3 R^2=.016, TOTAL2 R^2=.253, and TOTAL3 R^2=.409.

Reduced Model

The reduced model is represented in Figure 4 and includes standardized path coefficients. Only significant paths are shown. The reduced model provided an adequate fit to the data, χ^2 = 16.75 (P=.471), the Goodness of Fit index (GFI) =.991, the Adjusted Goodness of Fit Index (AGFI) =.971, The Root Mean Square Residual (RMR) =.215.

In the reduced model the structural equation accounted for 41% of the variance in the model (R^2=.407). The model explains 40% of the variance in TOTAL3; 25% of TOTAL2; 12% of FACTOR2, just 3% of FACTOR1 and none of the variance in FACTOR3.

Table 7. Standardized coefficients, and t-statistics for the saturated model (n=372).

	LNFAC1	LNFAC2	LNFAC3	TOTAL2	TOTAL3	SES	TMOT	TOTAL1	MPNS	MCNS
LNFAC1	.000	.000	.000	.000	.000	-.088	.169	.000	-.082	-.071
	(.000)	(.000)	(.000)	(.000)	(.000)	(-1.696)	(3.275)**	(.000)	(-1.124)	(-.967)
LNFAC2	.000	.000	.000	.000	.000	.000	.239	.000	.224	.000
	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(4.833)**	(.000)	(4.536)**	(.000)
LNFAC3	.000	.000	.000	.000	.000	.088	-.057	-.079	.000	.000
	(.000)	(.000)	(.000)	(.000)	(.000)	(1.673)	(-1.092)	(-1.508)	(.000)	(.000)
TOTAL2	-.055	.010	-.123	.000	.000	.086	.199	-.081	.000	.380
	(-1.189)	(.204)	(-2.074)*	(.000)	(.000)	(1.838)	(4.152)**	(-1.766)	(.000)	(8.020)**
TOTAL3	.005	-.019	-.045	.435	.000	.059	.070	.000	.164	.137
	(.122)	(-.435)	(-1.112)	(9.379)**	(.000)	(1.418)	(1.614)	(.000)	(2.805)**	(2.254)*

* = significant at the .05 level, ** = significant at the .01 level, () = t-statistic

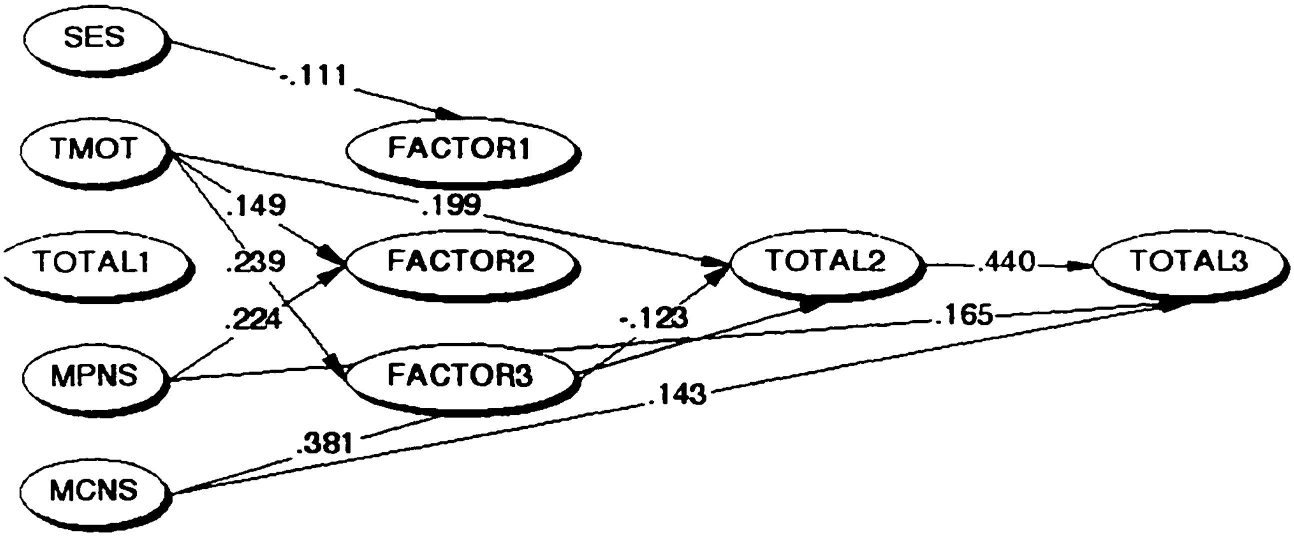


Figure 4. Reduced model with standardized path coefficients.

Summary

Data analysis produced evidence that the Student Technology Use instrument was reliable (alpha =.88, test/retest correlation = .86, p <.01). Factor analysis of the STU generated 3 latent factors which were described as: volume of computer/graphing calculator use, self-efficacy with computers/graphing calculators, and the Internet. The presence of the third factor was unexpected, but clear. This serves as evidence that the STU possesses construct validity by identifying 3 distinct elements of technology use.

Discriminant analysis showed the proposed model was a strong predictor of group membership for 6^{th}, 7^{th} and 8^{th} grade middle school math students. This finding was allowed to take precedence over the fact that there are significant differences between the groups.

Path analysis produced a final model that accounted for 41% of the variance and predicted 40% of the score on the final exemplar and 25% of the score on exemplar2. The model was a poor predictor of the 3 technology factors. Model fit was good with a non-

Table 8. Standardized coefficients and t-statistics for the reduced model (n-372).

	LNFAC1	LNFAC2	LNFAC3	TOTAL2	TOTAL3	SES	TMOT	TOTAL1	MPNS	MCNS
LNFAC1	.000 (.000)	.000 (.000)	.000 (.000)	.000 (.000)	.000 (.000)	-.111 (-2.146)*	.149 (2.891)**	.000 (.000)	.000 (.000)	.000 (.000)
LNFAC2	.000 (.000)	.000 (.000)	.000 (.000)	.000 (.000)	.000 (.000)	.000 (.000)	.239 (4.833)**	.000 (.000)	.224 (4.536)**	.000 (.000)
LNFAC3	.000 (.000)	.000 (.000)	.000 (.000)	.000 (.000)	.000 (.000)	.000 (.000)	.000 (.000)	.000 (.000)	.000 (.000)	.000 (.000)
TOTAL2	-.055 (-1.199)	.010 (.204)	-.123 (-2.724)**	.000 (.000)	.000 (.000)	.086 (1.841)	.199 (2.891)**	-.081 (-1.771)	.000 (.000)	.381 (8.083)**
TOTAL3	.000 (.000)	-.017 (-.392)	-.040 (-.991)	.440 (9.509)**	.000 (.000)	.000 (.000)	.072 (1.649)	.000 (.000)	.165 (2.821)**	.143 (2.355)*

significant χ^2, Goodness of Fit and Adjusted Goodnes of Fit indices close to 1.0 and a low Root Mean Square Residual. Model reduction was halted as the GFI and AGFI approached the same value.

CHAPTER FIVE: DISCUSSION

A number of studies have been done to determine whether or not instructional technologies have an impact on student learning. These studies commonly compared traditional instruction to instruction that included computers. A number of meta-analyses of these studies also produced generally positive results in favor of computer-based instruction. Educational theorists Richard Clark and Robert Kozma offer competing hypotheses about the influence of technology on learning. As discussed earlier (see chapter 2), Clark maintains that all learning is a result of instructional methods while Kozma asserts that technology also has an impact on learning.

This document reports a correlational study that employed path analysis techniques. The intent of this study was to contribute new evidence to the discussion of whether technology use or instructional method or both contributed to student learning outcomes. The study hypothesized that technology would interact with instructional method to impact student learning.

Following the recommendations of Martella, Nelson, and Marchand-Martella (1999) concerning the design of correlational studies, an hypothesis was created based on a review of the literature, a group of participants was selected that was homogeneous with respect to the desired variables, and instruments were developed which possessed adequate reliability and validity.

Hypothesis and Model Development

The literature in mathematics education suggested factors that contribute to student learning in mathematics including: motivation, socio-economic status, and prior knowledge. The literature on technology in education suggested technology use and instructional method could impact student learning.

Students' ITBS scores for math concepts/data analysis and for problem solving represented prior knowledge. The selected scores were the National Standard Scores. Motivation for learning mathematics was measured using an instrument derived from the work of Pintrich, which had demonstrated reliability and validity (1993). Socio-economic status was determined using free/reduced lunch status. For this purpose students were scored 1 if on free or reduced lunch status and 2 if no subsidy were provided. The Student Technology Use instrument was developed to measure technology use and scores on the math exemplars 1 & 2 represented instructional method. Math exemplar 3 was selected as the targeted learning outcome.

Student Technology Use Instrument

The Student Technology Use instrument demonstrated acceptable psychometric properties within the context of this study [Cronbach alpha = .88, test-retest reliability was .86 ($p < .01$)($n=48$)].

The instrument was found to have 3 distinct latent factors: volume of computer/graphing calculator use, self-efficacy with computers/graphing calculators, and the Internet. The emergence of the separate factor, which captured Internet usage, was unexpected. The sub-scales of the STU were thought to represent just two constructs: volume of use of technology and self-efficacy with technology. The presence of the Internet as a factor leads to several questions: How is Internet use different from computer/graphing calculator use? Could this represent another latent factor such as 'entertainment'?

The current study represents the pilot of the STU instrument. This should be followed by a wider test of the instrument using a random sample of students. Final description of the psychometric properties must await this next study. For now, it can be said that the STU seems to produce reliable results that represent 3 separate elements of the construct "technology use."

Impact of Method and Technology on Learning Outcomes

The goal of contributing new evidence to the discussion of the impact of technology on learning through this study was achieved only in part. The path analysis data provided mixed results. The three factors of student technology use did not impact the targeted learning outcome of Exemplar 3, which supports Clark's contention that technology itself has no impact on learning. On the other hand, only one of the two model elements representing instructional method contributed to Exemplar 3. Thus, the model failed to completely support Clark's assertion that instructional methods alone influence student learning.

Both of these results may have been confounded by conditions at the participating middle school. Discussions with participating teachers and a survey of the technology infrastructure at the school revealed that very little technology was used in the math classrooms. In fact, the single computer in the classroom was insufficient for use by students and the connection to the Internet was commonly unavailable due to network problems. Although teachers reported that students had access to hand-held calculators on a daily basis, no data was collected that supported that assertion. Also, the first exemplar, which did not contribute to the target outcome, may have been presented to the students before the pre-requisite skills were taught. Teachers have revised the timeline for exemplars during the second year to correct this problem.

These confounding conditions cast some doubt on the reliability of the conclusions presented by the path analysis in terms of its major goal, however, the data analysis did yield interesting information about the model elements.

Relationship of Model Elements

The path analysis of the full model provided important information about the relationship of the variables to the learning outcome – exemplar 3 (TOTAL3.) One finding of great interest is that SES did not have a significant impact on the learning outcomes in this study as either a direct effect or an indirect effect. This is contrary to Wenglinsky's (1998) finding that SES was the greatest contributor to learning outcomes. It should be noted that Wenglinsky's model included many but not all of the variables in the model described here. His model also included other variables not discussed here such as teacher professional development and ethnicity.

SES did have a significant negative impact on FACTOR1, the volume of computer and graphing calculator use. Wenglinsky (1998) reported that low-income students were given more basic skills review on computers. That could be one explanation of the finding that higher SES resulted in lower volume of computer/graphing calculator use.

Of all of the exogenous variables, TMOT made the greatest contribution in terms of direct and indirect effects on the endogenous variables. TMOT significantly and directly contributed to the prediction of FACTOR1, FACTOR2, TOTAL2 and TOTAL3. It also had significant indirect effects on TOTAL3 as mediated by TOTAL2. The impacts of TMOT on

TOTAL2 and TOTAL3 agree with Pintrich, Smith, Garcia and McKeachie's (1993) findings that high scores on motivation are correlated with high grades in a course.

The impact of motivation on the volume of computer/graphing calculator use (FACTOR1) and self-efficacy with computers and graphing calculators (FACTOR2) imply that students who are highly motivated to learn math will use computers/graphing calculators more often and will feel more confident in their skills related to computers/graphing calculator use. The explanation for this finding may lie in the construction of the motivation assessment. As described by Pintrich, Smith, Garcia and McKeachie (1993), the motivation scale includes a sub-scale that addresses feelings of self-efficacy in learning situations that could explain the effect on FACTOR2. Another sub-scale examines task value beliefs, it is understandable that those who value learning mathematics would employ the technologies that might facilitate the learning task.

The ITBS math concepts/data analysis score (MCNS) contributed directly and significantly to TOTAL2 and TOTAL3. This is not unexpected as higher levels of achievement in math concepts and data analysis might reasonably be expected to result in higher learning outcomes. In the case of the math program described in this study, this was welcome news as it was hoped that the ITBS scores and the exemplars chosen for use in the middle school would be aligned. The significant indirect effect of MCNS on TOTAL3 mediated by TOTAL2 suggests that these three (MCNS, TOTAL2 and TOTAL3 were so aligned. It also provides evidence that the teaching/learning activities of the classroom contributed to learning.

Similarly, the ITBS math problem solving score (MPNS) contributed significantly to TOTAL3. The explanation for why it did not impact TOTAL2 might rest on the content of the exemplars that comprised TOTAL2 at each grade level. Cursory examination of the tasks (See APPENDIX B) suggests that the TOTAL2 exemplars may require more data analysis than problem solving while TOTAL3 includes both skills. Although the final exemplars are intended to be summary assessments of the skills developed in the previous exemplars, it seems there were no other exemplars that addressed these problem-solving skills. This finding is a criticism of the middle school math program under study. If the beginning of the year math problem-solving scores directly predict the end-of-year scores, this suggests that the classroom activities do not impact the skills of problem-solving.

An unexpected significant direct effect of MPNS was found on FACTOR2. This implies that greater math problem solving skills are positively related to self-efficacy with computers and graphing calculator use. That is not an unreasonable assumption when considering the problem solving skills required learning to operate computer/calculator hardware and software.

TOTAL1 had no significant impact on the endogenous variables. This might be explained by the fact that TOTAL1 exemplars were presented near the beginning of the year during a review period. If so, it could represent the base line of student understanding of the skills required for success in later exemplars, but not contribute to the development of the higher-level skills. Alternatively, the lack of influence may reflect student inexperience in learning by constructivist strategies. It might be that students who were successful with the former teaching strategies had more trouble adapting to the new way of learning in math fostered by the constructivist activities. Or this finding could indicate the effect that teaching had on students between the administration of the first two exemplars. Further study is needed to determine which, if any, of these alternative explanations best explains the lack of impact of TOTAL1 on the other two exemplars.

Of the five endogenous variables, the only two that had significant direct effects on other endogenous variables were TOTAL2, which had a positive effect on TOTAL3, and FACTOR3 (the Internet), which had a significant negative effect on TOTAL3. The relationship between TOTAL2 and TOTAL3 underscores the interpretation of alignment of these exemplars and the importance of instructional method. The negative effect of the Internet on TOTAL2 suggests that perhaps students who spend lots of time on the Internet may not spend as much time learning mathematics. If a measure of entertainment elements were given and the results added to the factor analysis, a new factor for "entertainment" might emerge.

Conclusions & Implications

Of the 10 elements included in the path analysis model, socio-economic status, entering math achievement in problem-solving and math concepts are not elements that can be changed in a classroom setting. Motivation for learning mathematics, technology use and instructional method are elements that can be affected by classroom policies and activities. Motivation showed the greatest impact on all model elements in this study. Therefore, teachers should seek to increase student motivation employing tactics and strategies recommended in that body of research literature. Instructional method – constructivist methodology in this example - also received support in the path analysis data. Inclusion of these strategies in classroom activities is supported. Technology use was not supported in this study, but that cannot be interpreted as a condemnation of technology use due to the overall lack of technology use in the classrooms studied.

Limitations

This study was conducted at a single school, which represented a convenience sample, thus the results of this study cannot be generalized beyond this particular school. No representation is made that this school is representative of any others. Implications for practice made previously can only be applied to this situation.

Specific limitations within this study include the lack of technology use in a study designed to measure the impact of that use, lack of standardization of scoring of the exemplars across grade levels, lack of documentation of specific classroom uses of technologies including calculators, and absence of scores representing learning goals based on the Jasper Woodbury units.

Recommendations for Further Research

The path analysis technique has provided an interesting view into the complex relationships of technology, instructional methods and learning. Recommendations for further research include a flurry of small, carefully monitored studies examining the impacts of technology and instructional methods in many curricular areas and schools with differing levels of technology use. The current study suffered from a lack of involvement of researchers in the decisions made about teaching, scoring, and documentation of uses of technology.

The design of these research projects should focus special attention on scoring, content, and the cognitive requirements of student tasks. Attempts must be made to ensure that scoring, especially scoring based on rubrics, is applied consistently across classrooms and schools involved in the study. This can be achieved through such techniques as scorer training, establishing anchors for reference, and having teachers score each other's papers instead of their own. Content of the curriculum used in these studies must be specifically described and an effort made to ensure the assessments match the desired learning outcomes. The cognitive demands of student tasks must be monitored to be sure that they are rigorous and not just repetitions of teacher demonstrations. Attention to these details will improve understanding of the results of the model analysis.

It is recommended that future research employ the path analysis techniques and begin with the saturated model employed in this study. That model predicts a sizeable portion of the learning outcomes and would be a good place to begin further analyses.

A specific recommendation is to apply this model to the Every Student Counts program currently being conducted in this state. The program is a 3-year project to increase the use of technology and constructivist methodology in middle school math classes. The program has been adopted by 16 schools and includes professional development and coaching elements along with modeling of technology use in middle school math classrooms. This program would provide a fertile testing ground for the model because it includes specific elements aimed at increasing technology integration and constructivist teaching methodologies.

In addition to the research described, it is recommended that another method of describing the schools be employed so that the results may be generalizable. A suggestion for such a measure is the Engaged Learning/Technology battery (Phye, 2000) of instruments. The battery results in the placement of a school on a 2-by-2 matrix indicating levels of engaged learning practices and technology integration. If schools with common placement on the matrix experience similar learning outcomes, other schools with the same placement could reasonably suppose they would also achieve these outcomes.

Other foci of research could include further exploration of the links between motivation and technology use, between math problem solving skills and technology use, socio-economic status and technology use and Internet use and math achievement. This study has established that these variables are related, but does not answer the more important questions of how? and why?

Summary

Some of the results of the current study are readily explained such as the links between exemplar2 and exemplar3, the influence of ITBS math scores on exemplars, and motivation on exemplars. Other results are more difficult to address such as the finding that contrary to other studies, socio-economic status was not a significant influence on exemplar scores; the negative link between Internet use and exemplar scores, and the impact of math ability (ITBS scores) on self-efficacy with technology.

This study did not settle the dispute between Richard Clark and Robert Kozma concerning whether instructional methods alone or instructional methods coupled with technology use could produce student learning. Instead, it produced a model for path analysis that explained an unusually large amount of the learning outcome (41%) and established the reliability and construct validity of a measure of student technology use.

Further research recommendations include more studies focusing on specific applications of technology and method. These studies should employ the path analysis technique and begin with the saturated model that was described in this study.

APPENDIX A. STU INSTRUMENT

School #______44___ Class # __________ Student #__________

Student Technology Use Survey

Gender: ___female ___male Grade in school _____ How long have you been using computers?_______

Type of computer used at home (circle best answer): None Macintosh PC/Windows Both

Type of computer used at school (circle best answer): None Macintosh PC/Windows Both

1. How many TIMES a week do you use a computer:	0	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36+
a. at home?									
b. in the classroom?									
c. in a computer lab?									
d. in the media center?									
e. in any other location? (friend's house, office, etc.)									

2. How many TIMES a week do you use a graphing calculator:	0	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36+
a. at home?									
b. at school?									

3. How many HOURS a week do you spend using a computer or graphing calculator:	0	1-3	4-6	7-9	10+
a. playing games for fun?					
b. using educational software?					
c. doing Internet research for personal information?					
d. doing Internet research for school?					
e. email-ing friends and relatives?					
f. email-ing other students/resource persons for school?					
g. learning to use software?					
h. practicing keyboarding skills?					
i. conducting routine maintenance? (e.g. virus checking, optimizing, removing old programs/files?)					
j. using word processor for school assignments?					

3. How many HOURS a week do you spend using a computer or graphing calculator:	0	1-3	4-6	7-9	10+
k. to create multimedia presentations? (Using HyperStudio, Powerpoint, etc.)					
l. to analyze data with spreadsheets or with a database?					
m. to explore equations and figures?					
n. to model your thinking about math (Logo) or other subjects (Inspiration, etc.)					
o. to run educational simulations (not games)?					
p. to create web pages?					
q. to practice basic skills?					
r. for desktop publishing?					
s. to create graphics?					
t. to participate in chat rooms?					
u. to participate in listserves?					

4. (optional) List any other tasks for which you use a computer or graphing calcultor:

5. How confident are you in your ability:	No Confidence	Little Confidence	Average Confidence	Quite Confident	Extremely Confident
a. to do Internet research?					
b. to send/receive email?					
c. to use the keyboard?					
d. to conduct routine maintenance? (e.g., virus checking, removing old programs/files)					
e. to use a word processor?					
f. to use basic calculator functions?					
g.to practice estimation with a calculator					
h.to use a calculator to look for patterns in numbers?					
i. to use a calculator to find square roots?					
j. to use a calculator to graph basic linear functions?					
k. to use HyperStudio?					
l.. to use Powerpoint?					
m. to use spreadsheets?					
n. to create web pages?					
o. to do desktop publishing?					
p. to create graphics?					

The following questions ask about your motivation for and attitudes about this math class. Remember there are no right or wrong answers, just answer as accurately as possible. Use the scale below to answer the questions. If you think the statement is very true of you, circle 7; if a statement is not at all true of you, circle 1. If the statement is more or less true of you, find the number between 1 and 7 that best describes you.

Scale:

1	2	3	4	5	6	7
not at all true of me						very true of me

1. In math class, I prefer course material that really challenges me so I can learn new things.	1 2 3 4 5 6 7
2. If I study in the appropriate ways, then I will be able to learn the material in this math class.	1 2 3 4 5 6 7
3. When I take a math test I think about how poorly I am doing compared with other students.	1 2 3 4 5 6 7
4. I think I will be able to use what I learn in this math class in other classes.	1 2 3 4 5 6 7
5. I believe I will receive an excellent grade in math.	1 2 3 4 5 6 7
6. I'm certain I can understand the most difficult material presented in this math class.	1 2 3 4 5 6 7
7. Getting a good grade in math is the most satisfying thing for me right now.	1 2 3 4 5 6 7
8. When I take a math test I think about items on other parts of the test I can't answer.	1 2 3 4 5 6 7
9. It is my own fault if I don't learn the material in this math class.	1 2 3 4 5 6 7
10. It is important for me to learn math.	1 2 3 4 5 6 7
11. The most important thing for me right now is improving my overall grade point average, so my main concern in math is getting a good grade.	1 2 3 4 5 6 7
12. I'm confident I can learn the basic concepts taught in math.	1 2 3 4 5 6 7
13. If I can, I want to get better grades in math than most of the other students.	1 2 3 4 5 6 7
14. When I take math tests I think of the consequences of failing.	1 2 3 4 5 6 7
15. I'm confident I can understand the most complex material presented by the instructor in math class.	1 2 3 4 5 6 7
16. In math class, I prefer course material that arouses my curiosity, even if it is difficult to learn.	1 2 3 4 5 6 7

Scale:						
1 not at all true of me	2	3	4	5	6	7 very true of me

17. I am very interested in math.	1 2 3 4 5 6 7
18. If I try hard enough, then I will understand math.	1 2 3 4 5 6 7
19. I have an uneasy, upset feeling when I take a math test.	1 2 3 4 5 6 7
20. I'm confident I can do an excellent job on the assignments and tests in math class.	1 2 3 4 5 6 7
21. I expect to do well in math.	1 2 3 4 5 6 7
22. The most satisfying thing for me in math is trying to understand the content as thoroughly as possible.	1 2 3 4 5 6 7
23. I think math is useful for me to learn.	1 2 3 4 5 6 7
24. When I have the opportunity in math, I choose course assignments that I can learn from even if they don't guarantee a good grade.	1 2 3 4 5 6 7
25. If I don't understand math, it is because I didn't try hard enough.	1 2 3 4 5 6 7
26. I like math.	1 2 3 4 5 6 7
27. Understanding math is very important to me.	1 2 3 4 5 6 7
28. I feel my heart beating fast when I take a math test.	1 2 3 4 5 6 7
29. I'm certain I can master the skills being taught in this math class.	1 2 3 4 5 6 7
30. I want to do well in math because it is important to show my ability to my family, friends, employer, or others.	1 2 3 4 5 6 7
31. Considering the difficulty of this math class, the teacher, and my skills, I think I will do well in this math class.	1 2 3 4 5 6 7

APPENDIX B. MATH EXEMPLARS

Mathematics Standards for the XZY School District

1. Effectively uses a variety of strategies in the problem-solving process.
2. Understands and applies basic and advanced properties of the concept of numbers.
3. Uses basic and advanced procedures while performing the process of computation.
4. Understands and applies basic and advanced properties of the concept of measurement
5. Understands and applies basic and advanced properties of the concepts of geometry.
6. Understands and applies basic and advanced concepts of data analysis and probability.
7. Understands and applies basic and advanced properties of relationships, functions, and algebra.
8. Understands the general nature and uses of mathematics.

6th Grade Exemplars	Standards Met

1. "Gold Kit Dilemma" 1,3,7
Students must determine how to weigh gold in a jewelry store given a limited number of weights of specific sizes. Students will create a visual representation of their work and communicate their findings.

2. "Planely a Problem" 1,3,7
Students apply their number sense and place value knowledge to determine what combinations of luggage and passengers will result in a 10,000 pound payload for an airplane.

3. "Terrific Tiles" 1,2,3,4
Given 3 inch square tiles and a 10 x 15 foot floor, students must determine how many bundles of tiles to purchase to tile the kitchen floor. Students must create a visual representation and explain their solution.

4. "Who Owns the Most Land?" 1,2,3,4
Given a map of different plots of land and their valuations, students need to determine who has the most land and which land is most valuable. Students must explain how they solved the problem.

5. "Harvest Dinner" 1,2,3,4
Students need to calculate how much of each ingredient to purchase to make a meal for 300 people. They must show their work and explain how they

arrived at the answer.

6. "Taco Spread" 1,2,3,4
Given a fixed amount of one ingredient, students must calculate how much of the other ingredients must be purchased to create a taco spread using all of the one ingredient. Students must explain their solutions and show their work.

7th Grade Exemplars	Standards Met

1. "Winning Back the Dough" 1,2,3
Given a list of ingredients, the package size, cost per package and amount needed in recipe, students must determine whether it is cheaper to make pizza at home or buy it at a restaurant, or frozen in a store. Students must use their knowledge of fractions and decimals. Students must show their work and explain their answers.

2. "Who Wins the Dough" 1,2,3
Students must determine whether it is less expensive to make bread at home in a bread maker or purchase it at a store. Students will show their work and explain their answers.

3. "Stick Figure Dilemma" 1,2,3,4
This problem requires students to use non-standard measuring devices to determine the height of a figure. Students will use proportions to explain their answers.
4. "The Height Dilemma" 1,2,3,4

5. "CD Dilemma" 1,2,3,7
Given two different CD writers operating at different rates, students must calculate at what time will both machines have produced the same number of CD's.

6. "D. J. Dilemma" 1,2,3,7
Students must determine which of 2 DJ's offers the best rate for providing music for a wedding. Answers must be supported mathematically.

8th Grade Exemplars	Standards Met

1. "Stir Crazy" 1,2,3,6

Students must determine how many different stir-fry specials a new restaurant should be prepared to make and how many pounds of beef to have on hand for one month. This problem utilizes the "counting principle" and students need to make a math representation, show all work and explain their reasoning.

2. "Topping Trauma" 1,2,3,6

Students need to determine if it is possible to eat all possible combinations of 10 sundae toppings, 2 toppings at a time in one week. Students must represent the problem mathematically and explain their reasoning.

3. "The Display Dilemma" 1,2,3,5,7

Students must devise a rule for finding the number of boxes in a display that is 100 boxes in the base. Students must find the correct solution, make a mathematical representation, and explain their reasoning.

4. "Building Block Dilemma" 1,2,3,5,7

Students must find an equation which will give the number of blocks needed for any size tower. Students must make a mathematical representation, and explain their reasoning.

5. "Fences for Grazing" 1,2,3,4,5,

Given a 100 feet of fencing that requires poles every 5 feet, create a fenced in area which has the maximum area. Students must explain how they know the area fenced is the maximum. Solve it again using the 50 foot side of the barn as part of the fencing. Students must again explain their work and then compare the two solutions and draw conclusions.

6. "Doghouses" 1,2,3,4,5

Given a 150 cm x300 cm piece of plywood. Build the largest doghouse possible. Students must model the structure and explain how they know it is the largest possible solution.

Scoring Rubric for XYZ Middle School Math

Levels	Understanding	Reasoning	Accuracy	Communications
Novice	• I did not show that I understood the problem. • I did not address important parts of the task. • My solution does not use big math ideas.	• I did not use a strategy that helps solve the problem • The evidence for my claims does not make sense. • I did not make connections to the problem.	• My procedures are not organized for others to follow. • There are too many big mistakes in my work. • None of my items are labeled.	• I did not explain how my solution works to solve the problem. • I did not create designs to help explain the solution. • I did not use math language.
Apprentice	• I show a limited understanding of the problem. • I address some of the important parts of the task. • My big math ideas did not work very well to solve the problem.	• My strategies worked for part of the problerm. • I did not give clear evidence for my claims. • I tried to observe and make connections.	• My procedures are difficult for others to follow. • I have many mistakes in my work. • Some of my items are labeled.	• I did not explain how the problem was solved very well. • My visual designs do not match the solution. • I can use a little math language.
Practitioner	• I have a thorough understanding of the problem. • I address the important parts of the task. • I logically use big math ideas to solve the problem.	• I use effective strategies for the solutions. • I give evidence for my claims. • I can observe and make connections.	• My procedures are organized and can be followed by others. • If I made mistakes, they are not important ones. • I can label most of the items.	• I explain how I solve the problem. • I use visual designs to show my ideas. • I can use some math language.
Expert	• I can show a deep understanding of the problem. • I completely address all parts of the task. • I got it! I can use big math ideas to solve the problem.	• I can use powerful and thorough strategies to get to effective solutions. • I can explore, analyze, and justify all my claims. • I can observe and make connections beyond the problem to real-life situations.	• My procedures are organized so others can follow it. • All of my work is correct • I can label every item.	• I clearly explain how I solved the problem. • I use vital [sic] designs to show how my ideas match the solution. • I can use math language to explain my thinking.

Adapted by XYZ School District from © Exemplars

APPENDIX C. JASPER WOODBURY SCENARIOS

Available at: http://peabody.vanderbilt.edu/projects/funded/jasper/preview/jtcc.html

"Journey to Cedar Creek" Story Summary

Jasper Woodbury gets the newspaper from his mailbox. He goes straight to the boat section of the classifieds. He sees an ad for an old wooden boat: '56 Chris Craft CruiserNeeds work. See Sal at Cedar Creek. He decides to go to the Cedar Creek Boat Dock to look at the boat. He looks at a navigational map which shows that his dock is at mile 132.6. He guesses that it will take him about two hours to get to Cedar Creek if everything goes smoothly. As Jasper gets in his fourteen foot boat, the Sweetie ¼, he listens to the weather radio. The announcer says that the temperature is 91 degrees Fahrenheit (33 degrees Celsius); the sunset will be at 7:52 p.m. and the sunrise will be at 5:13 a.m.; the relative humidity is 85%; probability of rain is 50%; and the wind is from the west at 4 mph.

Jasper goes to Larry's to get gas. The pump at Larry's shows that the price for a gallon of gas is $1.29.9 with 4¢ off per gallon for cash. Jasper provides a pint of his own oil which he adds to the tank before Larry puts the fuel in. When Larry looks at the pump, he sees that Jasper has gotten 5.0 gallons for a total of $6.50. Larry says to Jasper, "You can't put much more than five gallons in a five gallon tank, now can you?" Larry gives Jasper change from a twenty dollar bill, which is all the cash Jasper has.

Jasper begins his trip to Cedar Creek. He is reminded of one of Larry's favorite axioms: Happiness is a day in the sun with a motor that runs and a full tank of gas. Jasper soon sees a tow of barges coming down the river. It was the size of two football fields. Actually it was nine barges tied together, three wide and three long. Each barge was 35 feet by 200 feet.

As Jasper continues down the river, he hits something in the water. He checks the propeller anddiscovers that there is a problem with it. He remembers that there is a repair shop somewhere nearby, so he rows to it. He rows into the repair shop which has the following signs: Willie Dixon's Boat Repair/ Hours 8 - 5/ Mile 140.3/No Credit Cards Accepted /Regular $1.109

The proprietor of the repair shop, Willie Dixon, takes a look at the Sweetie ¼. He says that the problem is with the shear pin and throws the broken shear pin to Jasper. Jasper drops it in the water and calls himself "Butterfingers." Willie replaces the bad shear pin. The total bill comes to $8.25.

As Jasper continues down river, he spots the Judge Robert Hickman, a ferry boat which is driven by a paddlewheel. Jasper is impressed, but he says that he is glad that a propeller is pushing him along because he is in a hurry to get to Cedar Creek to see the boat he saw advertised in the newspaper.

Jasper arrives at Cedar Creek Boat Dock, which is at mile 156.6. He says that he made it all the way to Cedar Creek on one tank of gas and that it took 80 minutes to get there from Willie's. Jasper gets directions to Sal's boat from a man at the dock.

Jasper meets Sal, and she tells him about the boat. The engines are 'twin 6's', both of them have 185 inch flat heads. They were rebuilt last year. She shows Jasper a fuel tank that a friend had built for her while the originals were being repaired. The dimensions of the temporary tank are 12 in x 12 in x 20 in. Sal tells Jasper that the boat burns about five gallons per hour at cruising speed. She also warns him that the running lights don't work, so she always gets home before the sun goes down.

Sal shows Jasper below deck. She shows him the "head" and tells him that the water tank holds about 30 gallons. She shows him the galley where she points out the icebox and describes the two ways she cooks when she is on board the boat. When she's hooked up to shore power, she uses a hot plate; when she's out on the river, she cooks with the alcohol stove. She shows him the kerosene heater that she uses in winter. Finally, Sal shows Jasper her library, and they agree that Tom Sawyer is a book they both enjoy reading. Jasper measures the berth and finds it is 76 inches long. He wanted to check if it was long enough for his 6 foot 2 inch height.

Jasper and Sal decide to go for a ride in the boat. Sal shows Jasper the ship-to-shore radio and the assortment of gauges on the boat: the fathometer, which shows how deep the water is; the "sniffer," which is a gauge that measures the level of explosive gas fumes in the engine compartment; and the tachometer, which indicates the revolutions per minute (rpm) of each engine.

While riding on the boat, they decide to find the speed needed to cruise at 1,600 rpms. They begin at mile marker 156.0 and end at mile marker 155.0. Jasper's stopwatch shows that it takes 7 minutes and 30 seconds to go between the two mile markers. They go back to Cedar Creek and tie up at the fuel dock. Before Sal fills it up, Jasper measures how much fuel is already in the tank. He finds it to be about half full. Sal then fills the tank by pumping 6 gallons.Sal treats Jasper to a pistachio ice cream cone. They settle on a price for Sal's boat, and Jasper pays her with his last check. He reminds himself that it is 2:35 p.m.

Challenge

When should Jasper leave for home?

Can he make it without running out of fuel?

"Rescue at Boone's Meadow" Story Summary

Larry Peterson, a friend of Jasper Woodbury, flies an ultralight plane over Cumberland City. Soon, Larry begins to teach Emily Johnson to fly the ultralight. He gives her some information about the plane: Its total weight is 250 pounds. It can carry a payload of up to 220 pounds. Larry explains that payload is the weight the plane can safely carry in addition to its own weight; payload includes the weight of the pilot, the fuel, and cargo. Larry then shows Emily a box used for carrying extra cargo. The box weighs ten pounds when it is empty. The cargo box holds a 1-gallon gas can. Emily comes closer to the ultralight so she can see as Larry is teaching her. He explains that the propeller does the pushing, just like it does with a boat; the wing does the lifting. He then demonstrates how the unique shape of the wing helps lift the plane.

A few days later Larry teaches Emily about the engine of the ultralight. He tells her that his ultralight's engine was originally used for a snowmobile, so it uses regular fuel and not aviation fuel. The net weight of the five gallon fuel tank is 30 pounds. Emily points out that one and one-half gallons of fuel are left in each of the two sides of the fuel tank. She asks Larry how far he flew on the two gallons missing from the tank. He tells her that he had filled up the fuel tank in the morning and had flown over to Headlyville and back which was about 30 miles. She asked him how long that took. Larry replied, "My rule of thumb is onemile every two minutes ‹ on a calm day, that is." Larry tells Emily that he only needs a field 100 yards long to take off.

A few weeks later Emily takes her first flight. Emily, Larry, and Jasper go out to supper to celebrate. At the restaurant, Jasper talks about his plans for a fishing trip. He says that he plans to drive the 60 miles from Cumberland City to Hilda's Service Station and then hike to his favorite fishing spot, which is about 18 miles on foot. Larry mentions that he flew his ultralight to see Hilda the previous week and that he landed in the field next to her service station.

For dessert, Emily orders a dish of strawberry ice cream and Larry orders lemon jello in a sugar cone. Their bill comes to $17.50. Emily suggests they include a 20% tip, and they agree to split the check equally. They each put money down on the table: Jasper puts $11.00 down, Emily puts $12.00, and Larry puts $9.00 down. Larry calculates thetotal bill and makes change for each of them. Before leaving the restaurant, Emily and Larry weigh themselves. The scale shows that Emily weighs 120 pounds and Larry weighs 180 pounds. While fishing, Jasper hears a gunshot. He discovers that an eagle has been shot. After giving first-aid to the eagle, he makes an emergency call to Hilda on his two-way radio.

A customer in a convertible drives up to Hilda's. The speed limit on the road is 60 miles per hour. Hilda is pumping gas for her customer as Jasper radios for help. When Hilda is finished, the gas pump shows that the customer got a total of 13.9 gallons and that gas costs $1.259 per gallon. Her customer records his mileage and tells Hilda that he got 312 miles on his last tank of gas. His bill for the gas comes to $17.50, and he pays for it with a $20.00 bill. When Hilda answers Jasper's emergency call, Jasper tells her about the wounded eagle and explains that he needs to get it to Dr. Ramirez, a veterinarian in Cumberland City, ASAP. Jasper tells Hilda that he is at Boone's Meadow, which is about a five hour walk from her service station. He asks Hilda to call Emily Johnson and explain the situation.

Emily drives to Dr. Ramirez's office. They go into his office where he has a map of the area on his wall. He marks the locations of his office in Cumberland City, Boone's Meadow, and Hilda's. Dr. Ramirez points out that Hilda's is right off the highway and that there are no roads leading into Boone's Meadow. Emily asks how much a bald eagle weighs. Dr. Ramirez estimates that it would weigh about 15 pounds.

On the map, Dr. Ramirez determines that the distance by air between Boone's Meadow and Cumberland City is about 65 miles. He tells Emily that most planes need about 2,000 feet of runway and Boone's Meadow is just half that long. Before he leaves, Dr. Ramirez tells Emily that the sooner he can treat the eagle, the better chance he has of saving it.
Emily plans for the eagle's rescue. She uses the map to determine that the distance by air between Boone's Meadow and Hilda's is approximately 15 miles. Next, she calls Larry, who is just down the road. She learns that Larry is available to fly, that the ultralight is fueled up and ready, and that the winds are calm. Emily thinks about the information she has gathered. She estimates that if the ultralight is used in the rescue, she had better add five minutes for each stop.

Challenge: Emily wants to know two things:
The quickest way to move the eagle to Cumberland City?
And how long will that take?

"The Big Splash ": Story Summary

Chris walks to the local fire station to do some research for a report he is writing. As he walks toward the fire hall, he see a city truck cleaning the streets with water. The truck has the following sign on it:

Department of Public Works
Capacity 3,000 gal

When Chris arrives at the fire hall, he meets Chief Sullivan, the fire chief. Chief Sullivan shows Chris the pumper truck which can pump 1000 gallons a minute, assuming they are hooked up to a hydrant. Chris asks if they usually find a hydrant, and Chief Sullivan says that usually they do, assuming they are in the city. Chief Sullivan says that the pumper truck holds some water (the sign says 'capacity 700 gallons'), but it doesn't hold enough water to do much fire fighting. Chief Sullivan then shows Chris the 38 foot ladders. Chris asks how often the firefighters go out on fires. Chief Sullivan says that they average 20 to 30 calls a week, although some of the calls are false alarms.

Chris sees a "weird looking contraption" in the fire hall. Chief Sullivan says that it is a dunking machine that they built. He says that they sometimes sell 100 tickets per hour. They rent it out for $25.00 per day, and the proceeds go to their scholarship fund. Chris asks where they put the water. Chief Sullivan says that they set it up in an above-ground swimming pool. Chris then asks the chief to see the pole which firefighters slide down when there is a fire.

Thursday afternoon, as Chris sits in school, he listens to an announcement about the upcoming Fun Fair. The principal, Ms. Stieger, announces that the fair will be held a week

from Friday from 10:00 A.M. to 3:00 P.M. on the athletic field. She says that the proceeds will go toward a new video camera for the student television station. She also says that they hope to raise $800, and they need at least one more good money making project for the fair. The school will loan someone up to $150.00 to cover the initial costs of their project. Plans need to be given to her by Wednesday. As Chris listens to the announcement, he daydreams about his teacher getting drenched as he is dunked by a dunking machine. Two formulas, V = ¼r2 x h and ¼ ‰ 3.14, are shown on the board behind the teacher. Later that afternoon, Chris goes to Ms. Stieger to find out what he needs to do to have a booth in the Fun Fair. She tells him that he needs to write a business plan that describes how much money he expects to take in, his gross revenue, and how he arrived at that number. Secondly, she needs an itemized account of all his expenses. The expenses cannot exceed $150.00, the maximum amount
she can loan him. The plan needs to include everything he will need so that she can see that everything will be in the right place at the right time. Her rule of thumb is that if everything looks good and the revenue is at least twice his expenses, the project is viable and she can make him the loan.

Later, Chris meets Jasper at the Soda Shop to talk about his plan. Jasper asks Chris how many students go to his school. Chris has already researched this and found that there are 380 students enrolled in the school, and on an average day, twenty are absent. Jasper says it would be nice to know how many students would buy tickets. Chris estimates that more than half probably would. Chris and Jasper decide a survey would be a good way of getting a more accurate estimate. Chris hands out surveys to every sixth student in line going into the school cafeteria during lunchtime on Friday. The survey asks the following:

Sometimes at fairs, you'll see one of those dunking machines. When you hit the target with a ball, a person will fall in the water.
1. Would you like to "dunk" one of your teachers at the All-School Fair?
Circle one Yes No

2. What's the most you would pay for one ticket (2 throws)?
Circle one A. $0.50 B. $1.00 C. $1.50 D. $2.00

That afternoon, Chris meets with Jasper again at the Soda Shop. They look at the results of Chris' survey. Chris says that 58 out of 60 students would like to dunk a teacher. He shows Jasper the rest of the results:

$0.50	13 kids
$1.00	21 kids
$1.50	16 kids
$2.00	8 kids

They begin to figure out how much money Chris would make if he charged the different amounts for tickets based on his survey results. Jasper says that all 58 students would pay at least $ .50 for a ticket. Chris multiplied 58 times $ .50 and got $29.00. Next, Chris says that all but 13 students would spend at least $1.00 for a ticket. To determine how many students would pay $1.00 for a ticket, Chris adds 21, 16, and 8 and gets an answer of 45. Jasper has to leave, so Chris continues to find what the best ticket price would be on his own.

On Saturday, Jasper and Chris meet Janet Foster, the proprietor of Penguin Pools. She says that she usually does not rent pools, but since Chris is doing this for a school project, she might make an exception. Ms. Foster shows them a pool that she thinks might be just what he needs. It is 3 feet deep and 12 feet in diameter. It holds about 2500 gallons of water. She will rent it to Chris for $40 a day, in advance, and she will give him one-fourth off for the second day if he needs it. Jasper asks if this price includes delivery.

Ms. Foster shows them a price sheet:

Set-up Hours	Days	Price
	Days	
6am to 6pm	Mon- Fri	$7/hr
6am to 12 noon	Saturday	$10/hr

Water Delivery: $15/load (load = 1,500 gal) plus mileage
Mileage = $1.15/mi (one way; return trip free)
Water Pickup: (1,500 gal maximum) $10 flat fee

Ms. Foster says that Harold, her set up man, figures it takes about two hours to set a pool up or take it down, and he will start at 6 a.m., but he won't work past 6 p.m. Chris asks if two hours includes filling the pool. Ms. Foster says, "No, it doesn't. So be sure to allow yourself plenty of time up front to fill the pool, especially if you are going to fill it from a hose." Ms. Foster points out that Chris could buy the water from her. It costs $15 a load plus mileage; her truck holds 1500 gallons. She says that it takes about 15 minutes to pump water in or out of the pool. Ms. Foster says there are 7.5 gallons in a cubic foot of water. Chris and Jasper leave the pool store with 45,836.5 miles showing on the odometer. They arrive at the school (odometer reading: 45,845.4 mi) to test how quickly water comes out of the water hose. It takes them 20 minutes to get to the school from the pool store. When they arrive at school, they walk past a fire hydrant to get to the hose. It takes 30 seconds to fill a five gallon bucket with water from the school's water hose.

Sunday afternoon, Chris goes back to the fire hall to talk to Chief Sullivan. Chief Sullivan says that Chris can use the machine for a day, and they'll bring it over Thursday afternoon. Chris asks if they can begin filling it up at 8:30 Friday morning. Chief Sullivan agrees and says that they can use the pumper truck to fill the pool, which will only take a few minutes. Chris won't have to pay anything for the fill up because it's a school project. He emphasizes that if the firefighters are out on a call, they won't be able to help until they get back.

Tuesday afternoon, Chris and Jasper meet at the Soda Shop. Jasper is reading the newspaper. Chris sees an article that says that the Public Works Department will drain swimming pools free of charge. Concerned citizens should call the Mayor's Office between 8 a.m. and 5 p.m. Chris says that he will be presenting his plan to Ms. Stieger the next day.

Challenge

Five teachers have told Chris that they are willing to be dunked. Prepare a business plan for the dunking machine project as if you were making the presentation to Ms. Stieger.

And how long will that take?

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